भारतीय मानक
Indian Standard

IS 14901 (Part 3) : 2016
IEC 60747-3 : 2013

अर्धचालक उपकरण — विविक्त उपकरण

भाग 3 सिग्नल, स्विचिंग एवं नियामक डायोड

Semiconductor Devices — Discrete Devices

Part 3 Signal, Switching and Regulator Diodes

ICS 31.080.10

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November 2016 **Price Group 11**

Electronic Components and Modules Sectional Committee, LITD 05

NATIONAL FOREWORD

This Indian Standard (Part 3) which is identical with IEC 60747-3 : 2013 'Semiconductor devices — Discrete devices — Part 3: Signal, switching and regulator diodes' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Electronic Components and Modules Sectional Committee and approval of the Electronics and Information Technology Division Council.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminology and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.
b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appear to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard, which is to be substituted in its place, is listed below along with its degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60747-1 : 2006 Semiconductor devices — Part 1: General	IS 14901 (Part 1) : 2010 Semiconductor devices: Discrete devices and integrated circuits: Part 1 General (*first revision*)	Identical

The technical committee has reviewed the provisions of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60050 (All parts)	International Electrotechnical Vocabulary

Only the English language text of the IEC Standard has been retained while adopting it as an Indian Standard, and as such the page numbers given here are not the same as in the IEC Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

IS 14901 (Part 3) : 2016
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Indian Standard

SEMICONDUCTOR DEVICES — DISCRETE DEVICES

PART 3 SIGNAL, SWITCHING AND REGULATOR DIODES

1 Scope

This part of IEC 60747 gives the requirements for the following devices:

- signal diodes (excluding diodes designed to operate at frequencies above several hundred MHz);
- switching diodes (excluding high power rectifier diodes);
- voltage-regulator diodes;
- voltage-reference diodes;
- current-regulator diodes.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary*
(available at <http://www.electropedia.org>)

IEC 60747-1:2006, *Semiconductor devices – Part 1: General*
Amendment 1:2010

3 Terms, definitions and graphical symbols

For the purposes of this document, the terms and definitions given in IEC 60050-521, IEC 60050-702 and IEC 60747-1, and the following, apply.

3.1 Signal and switching diodes

3.1.1
forward recovery voltage
v_{FR}
forward voltage occurring during the forward recovery time after switching from zero or a reverse voltage to a forward current

3.1.2
detector voltage efficiency
η_{V}
ratio of the d.c. load voltage to the peak sinusoidal input voltage under specified circuit conditions

3.1.3
detector power efficiency
η_p
ratio of the change in d.c. power in the load resistance produced by the a.c. signal, to the available power from a sinusoidal voltage generator when the diode is operated under specified conditions

3.1.4
repetitive pulse energy
E_PR
energy of a pulse of short duration that occurs in a repetitive series of pulses

3.1.5
total capacitance
C_tot
capacitance at the diode terminals, measured under specified bias conditions

3.2 Voltage reference diodes and voltage regulator diodes

3.2.1
voltage reference diode
voltage regulator diode where the minimum and maximum voltages are both specified at the same current

[SOURCE: IEC 60050-521:2002, 521-04-16 modified – rewritten]

3.2.2
working direction
direction of current that results when the N-type semiconductor region is at a positive voltage relative to the P-type region

Note 1 to entry: This is also the reverse direction for voltage regulator diodes.

3.2.3
regulating range
range of working direction currents within which the voltage is maintained between specified limits

3.2.4
working current
I_Z
current within the regulating range

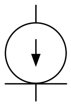
3.2.5
working voltage
V_Z
voltage within the regulating range

3.2.6
differential working resistance
r_z
differential resistance at a working current within the regulating range

3.2.7
temperature coefficient of working voltage
α_VZ
the quotient of the change in working voltage between two specified values of temperatures ,and the difference between these two temperatures

3.3 Current-regulator diodes

3.3.1 Graphical symbol



NOTE The arrow denotes the direction of flow of the regulator (working) current, flowing from the anode to the cathode. This is termed the forward direction for current-regulator diodes, and the terms defining the forward and reverse directions of a PN junction (IEC 60050-521:2002, 521-05-03 and 521-05-04) do not apply.

Figure 1 – Current-regulator diode graphical symbol

3.3.2
regulator voltage
V_S
voltage within the regulating range of a current-regulator diode

Note 1 to entry: “Working voltage” is no longer the preferred term.

3.3.3
limiting voltage
V_L
voltage at point I_L on the current-voltage characteristic

SEE: Figure 2.

3.3.4
knee voltage
V_K
voltage near the lower knee of the current-voltage characteristic

3.3.5
regulator current
I_S
current within the regulating range of a current-regulator diode

Note 1 to entry: “Working current” is no longer the preferred term.

3.3.6
limiting current
I_L
specified current below the regulating range

3.3.7
small-signal regulator conductance
g_s
small-signal conductance within the regulating range of a current-regulator diode

3.3.8
knee conductance
g_k
small-signal regulator conductance at the knee voltage

3.3.9
temperature coefficient of regulator current

α_{IS}

quotient of the change in regulator current between two specified values of temperature and that change of temperature

Note 1 to entry: The change in regulator current is usually expressed as a percentage of regulator current.

Note 2 to entry: "Regulator current" is now used instead of "working current", which is no longer the preferred term.

4 Letter symbols

4.1 General

The general rules and letter symbols of IEC 60747-1:2006, Clause 4 apply with the following additions.

4.2 Signal and switching diodes

4.2.1 Subscripts

A, a	anode
K, k	cathode
r	recovery, recovered
S, s	storage, stored

4.2.2 List of letter symbols

4.2.2.1 Voltages

V_{F}	Continuous (direct) forward voltage
V_{R}	Continuous (direct) reverse voltage
V_{RM}	Peak reverse voltage
$V_{\mathrm{(BR)}}$	Breakdown voltage
v_{FR}	Forward recovery voltage
V_{FRM}	Peak value of forward recovery voltage

4.2.2.2 Currents

I_{F}	Continuous (direct) forward current
i_{F}	Instantaneous forward current
I_{FM}	Peak forward current
I_{R}	Continuous (direct) reverse current
i_{R}	Instantaneous reverse current
I_{RM}	Peak reverse current

4.2.2.3 Switching characteristics

t_{fr}	Forward recovery time
t_{rr}	Reverse recovery time
i_{rr}	Reverse recovery current
Q_{r}	Recovered charge

4.2.2.4 Sundry quantities

r	Differential resistance

η_{p}	Detector power efficiency
η_{v}	Detector voltage efficiency
E_{pr}	Repetitive pulse energy

4.3 Voltage reference diodes and voltage regulator diodes

4.3.1 Subscripts

Z, z	working

4.3.2 List of letter symbols

4.3.2.1 Voltages

V_{Z}	Working voltage
V_{nz}	Noise voltage within the working voltage range (V_{n} is also acceptable if no misunderstanding is possible).

4.3.2.2 Currents

I_{Z}	Continuous (direct) reverse current within the working voltage range
I_{R}	Continuous (direct) reverse current at a voltage below the working voltage range

4.3.2.3 Sundry quantities

r_{z}	Differential (working) resistance
α_{vz}	Temperature coefficient of working voltage (Reserve symbol: S_{z})

4.4 Current-regulator diodes

See Figure 2.

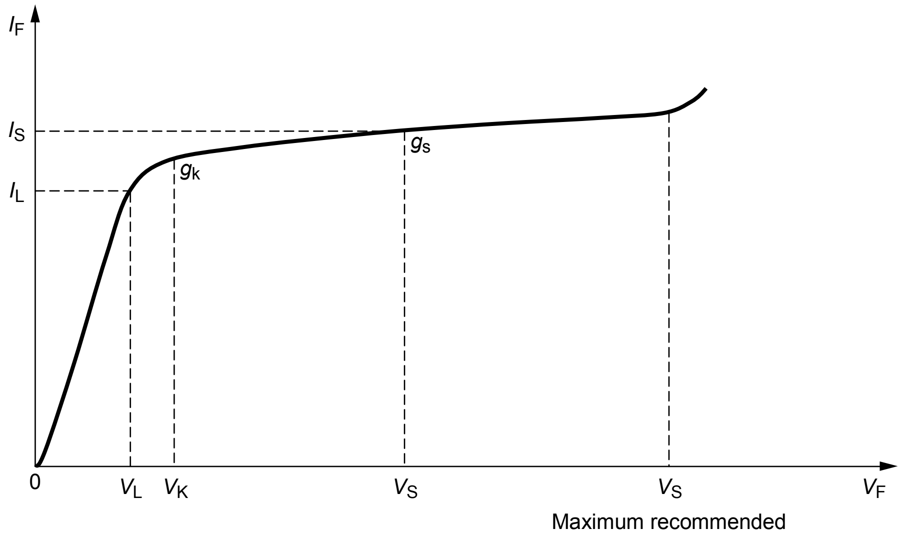


Figure 2 – Current-regulator diode characteristic with symbol identification

4.4.1 Subscripts

S, s	Regulator
L	Limiting
K	Knee

4.4.2 List of letter symbols

4.4.2.1 Voltages

V_S	Regulator voltage
V_L	Limiting voltage
V_K	Knee voltage

4.4.2.2 Currents

I_S	Regulator current
I_L	Limiting current

4.4.2.3 Sundry quantities

g_s	Small-signal regulator conductance
g_k	Knee conductance
ΔI_S	Regulator current variation

5 Essential ratings and characteristics

5.1 General

The rules of IEC 60747-1:2006, Clause 5 apply, with the following additions.

Voltage and current ratings apply over the rated range of operating temperatures. Where such ratings are temperature-dependent, this dependence should be indicated.

5.2 Signal and switching diodes

5.2.1 Ratings (limiting values)

5.2.1.1 Minimum and maximum storage temperatures (T_{stg})

5.2.1.2 Minimum and maximum operating ambient or case temperature (T_a or T_c)

5.2.1.3 Maximum continuous (direct) reverse voltage (V_R)

5.2.1.4 Maximum peak reverse voltage (V_{RM})

Under specified pulse conditions (for switching diodes).

5.2.1.5 Maximum continuous (direct) forward current (I_F)

5.2.1.6 Maximum peak forward current (I_{FM})

Under specified conditions.

5.2.1.7 Maximum total power dissipation (P_{tot} or P_C)

Where thermal resistance is not given in the characteristics, maximum total power dissipation as a function of temperature over the range of operating temperatures shall also be given.

5.2.1.8 Any special requirements for ventilation and/or mounting

5.2.2 Characteristics

5.2.2.1 Reverse current (I_R)

Maximum value at the maximum continuous (direct) reverse voltage and at a low value of reverse voltage at 25 °C and one higher temperature.

5.2.2.2 Forward voltage (V_F)

Maximum value at the rated maximum continuous (direct) forward current at 25 °C.

Minimum value at low value of continuous (direct) forward current at 25 °C.

5.2.2.3 Total capacitance (C_{tot})

Maximum value at specified low value of reverse voltage at 25 °C; the frequency shall be below that where secondary effects are significant.

5.2.2.4 Recovered charge (Q_r)

For switching diodes: maximum value when switching from a specified forward current by the application of specified reverse voltage or current and for specified circuit conditions.

NOTE See note in 5.2.2.5.

5.2.2.5 Reverse recovery time (t_{rr})

For switching diodes: maximum value when switching from a specified forward current by the application of specified reverse voltage or current and for specified circuit conditions. See Figure 3.

NOTE Recovered charge and reverse recovery time are measured between the instant when the current passes through zero, when changing from the forward direction to the reverse direction (t_0), and the instant when the reverse current is reduced from its peak value I_{RM} either to a specified low value (preferably 10 % of the peak reverse current) (t_I), or when the extrapolated reverse current reaches zero (t_{rr}). The extrapolation is carried out with respect to two specified points, preferably 90 % and 25 % of the peak reverse current.

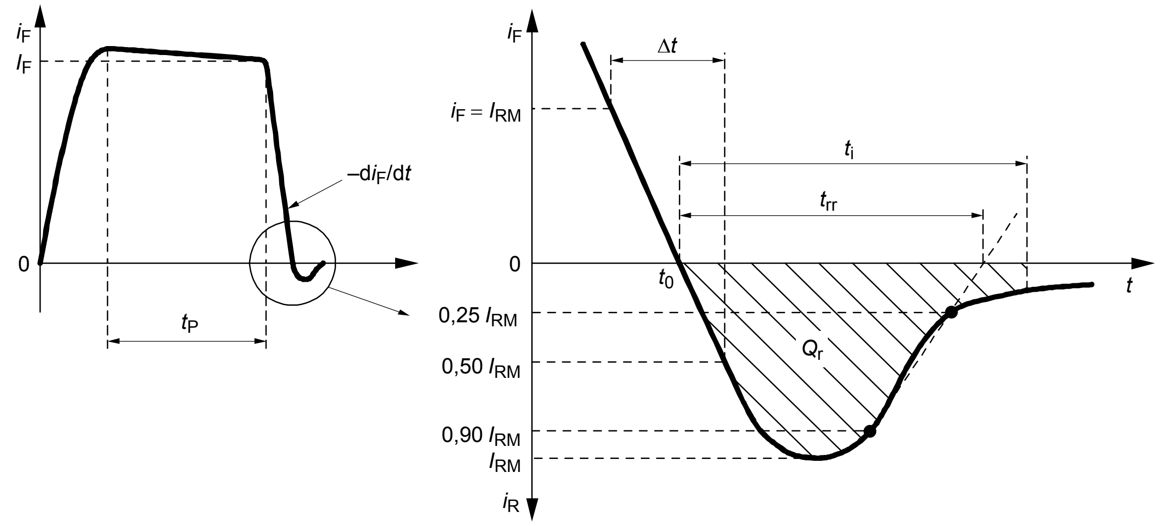


Figure 3 – Reverse recovery current waveform

5.2.2.6 Peak forward recovery voltage (V_{FRM})

Maximum value (where appropriate) when switching from a specified reverse voltage to a specified forward current.

5.2.2.7 Forward recovery time (t_{fr})

Maximum value (where appropriate), when switching from a specified reverse voltage (preferably zero) by the application of a specified forward current with a specified rise time between 10 % and 90 %.

NOTE Forward recovery time is measured between the instant when the forward voltage rises through a specified first value (preferably 10 % of the final stable value) and the instant when it falls from its peak value, either to a specified second value close to the final stable value (preferably 110 %) or when the extrapolated forward voltage reaches zero (the extrapolation is carried out with respect to two specified points, preferably 90 % and 50 % of the peak forward voltage). See Figure 4.

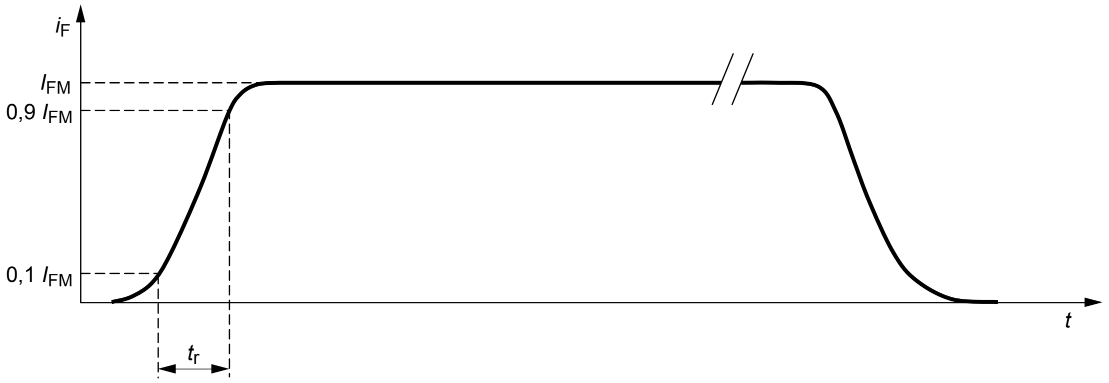


Figure 4 a) Current waveform

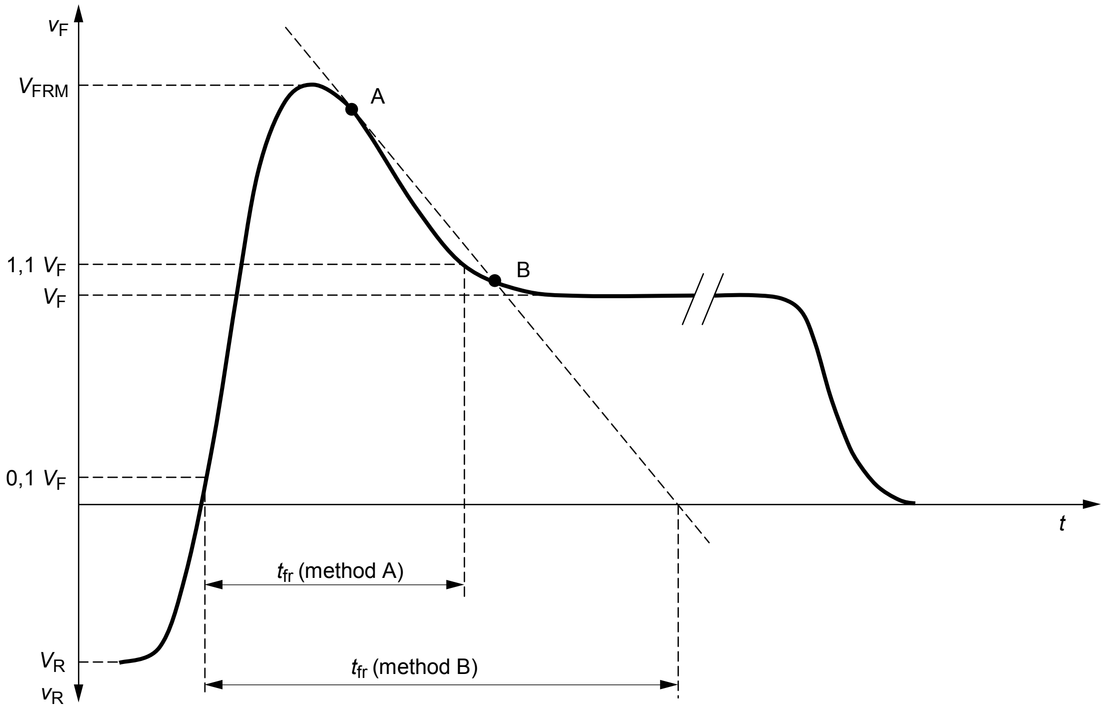


Figure 4 b) Voltage waveform

Figure 4 – Current and voltage waveforms

5.2.2.8 Detector efficiency

For diodes specified for use in detector circuits, the following characteristics shall be stated:

Either: **a) Detector voltage efficiency (η_v)**

Minimum value (for high-level RF detectors) under specified bias conditions at 25 °C. The circuit conditions and the frequency of measurement shall also be specified.

Or: **b) Detector power efficiency (η_p)**

Minimum value (for low-level RF detectors) under specified bias conditions at 25 °C and at one higher temperature. The circuit conditions and the frequency of measurement shall also be specified.

5.2.2.9 Noise (V_n, I_n) (where appropriate)

Maximum value of noise voltage or current, depending respectively on whether the diode is forward or reverse biased.

5.3 Voltage reference diodes and voltage regulator diodes

5.3.1 Ratings (limiting values)

5.3.1.1 Minimum and maximum storage temperatures (T_{stg})

5.3.1.2 Minimum and maximum operating ambient or case, temperature (T_a or T_c)

5.3.1.3 Maximum continuous (direct) reverse current (I_Z)

5.3.1.4 Maximum continuous (direct) forward current (I_F)

(For diodes intended for operation in the forward conductivity region).

5.3.2 Characteristics

5.3.2.1 Working voltage (V_Z)

Nominal, minimum and maximum values, each at a specified current in the scale 1, 2, 5 and preferably with either T_c or T_a and mounting details specified. Alternatively, the conditions may be at a specified T_{vj} and a pulse test method be used, taking into account 6.2.2.

For voltage-reference diodes, the preferred nominal values of working voltages are shown in Table 1 and Table 2. The nominal values in the tables multiplied by 10 are the recommended values for higher voltages. The specified minimum and maximum limits shall not lie outside those shown in the tables.

Table 1 – Preferred reference diode working voltages – Voltages in the E24 series

Min.	Nom.	Max.	Min.	Nom.	Max.	Min.	Nom.	Max.
2,5	2,7	2,9						
2,8	3,0	3,2	5,8	6,2	6,6	12,4	13,0	14,1
3,1	3,3	3,5	6,4	6,8	7,2	13,8	15,0	15,6
3,4	3,6	3,8	7,0	7,5	7,9	15,3	16,0	17,1
3,7	3,9	4,1	7,7	8,2	8,7	16,8	18,0	19,1
4,0	4,3	4,6	8,5	9,1	9,6	18,8	20,0	21,2
4,4	4,7	5,0	9,4	10,0	10,6	20,8	22,0	23,3
4,8	5,1	5,4	10,4	11,0	11,6	22,8	24,0	25,6
5,2	5,6	6,0	11,4	12,0	12,7	25,1	27,0	28,9

Table 2 – Preferred reference diode working voltages – Voltages in the E12 series

Min.	Nom.	Max.	Min.	Nom.	Max.	Min.	Nom.	Max.
2,4	2,7	3,0						
2,9	3,3	3,6	6,1	6,8	7,5	13,0	15,0	16,5
3,5	3,9	4,3	7,3	8,2	9,1	16,0	18,0	20,5
4,2	4,7	5,2	9,0	10,0	11,0	20,0	22,0	24,5
5,0	5,6	6,2	10,5	12,0	13,5	24,0	27,0	30,0

5.3.2.2 Differential resistance within the working voltage range (r_z)

Maximum value at the current specified in 5.3.2.1.

Maximum value at a recommended minimum operating current.

5.3.2.3 Temperature coefficient of working voltage (α_{vz})

Minimum and maximum values (percent per degree Celsius) at the current specified in 5.3.2.1. If this coefficient varies significantly with the temperature, the variation shall be stated, and the temperatures (preferably junction temperatures) at which the measurements are made shall be specified.

5.3.2.4 Junction capacitance

Maximum value (where appropriate) at a specified reverse voltage below the minimum working voltage.

5.3.2.5 Reverse current (I_R)

Maximum value at a specified reverse voltage below the minimum working voltage.

5.3.2.6 Forward voltage (V_F)

Maximum value at the maximum continuous (direct) forward current (where appropriate – for voltage-regulator diodes intended for operation in the forward region).

5.3.2.7 Noise voltage within the working voltage range (V_{nz})

Maximum value (where appropriate) under specified conditions of frequency, bandwidth and operating current. Where the variation of this characteristic with temperature is significant, this shall be specified.

5.4 Current-regulator diodes

5.4.1 Ratings (limiting values)

5.4.1.1 Minimum and maximum storage temperatures (T_{stg})

5.4.1.2 Minimum and maximum operating ambient or case, temperatures (T_a or T_c)

5.4.1.3 Maximum total power dissipation at an ambient or case temperature of 25 °C (P_{tot}) and a derating curve or derating factor

5.4.1.4 Maximum reverse voltage / Maximum reverse current

Either: a) Maximum reverse (negative anode-cathode) voltage (V_R)
or: b) Maximum reverse current (I_R)

(Where appropriate)

5.4.1.5 Maximum forward voltage (V_F)

(Where appropriate)

5.4.2 Characteristics

5.4.2.1 Regulator current (I_{S1})

Minimum and maximum values at a specified operating voltage (V_{S1}).

5.4.2.2 Regulator current (I_{S2})

Maximum value at the maximum recommended operating voltage (V_{S2}).

5.4.2.3 Temperature coefficient of regulator current (α_{IS})

Highest (most positive or maximum) and lowest (most negative or minimum) values at the operating voltage specified in 5.4.2.1 and specified range of T_a or T_c.

5.4.2.4 Regulator current variation / Small-signal regulator conductance

Either: a) Regulator current variation (ΔI_S)

Maximum value for a specified change of V_S between two specified values of V_S on either side of V_{S1}

Or: b) Small-signal regulator conductance (g_s)

Maximum value at V_{S1} and f = 1 kHz

5.4.2.5 Limiting voltage (V_L)

Maximum value at specified current (I_L), preferably 0,8 I_{S1} min

5.4.2.6 Where appropriate, knee conductance (g_k)

Maximum value at specified voltage (V_K) and f = 1 kHz

6 Measuring methods

6.1 General

The rules of IEC 60747-1:2006, Clause 6 apply.

In particular, IEC 60747-1:2006, 6.2 applies if pulse measurements are used in place of any of the d.c. methods specified below. In these cases:

- the variable generator is replaced by a pulse generator;
- the voltmeter is replaced by a peak-reading instrument;
- the ammeter is replaced by a peak-reading;
- pulse width and duty cycle (t_p, δ) shall be specified. Preferably: t_p, = 300 µs, $\delta \leq 2$ %.

6.2 Signal and switching diodes

6.2.1 Reverse current I_R

a) *Purpose*

To measure the reverse current of a diode under specified reverse voltage.

b) *Circuit diagram* (Figure 5)

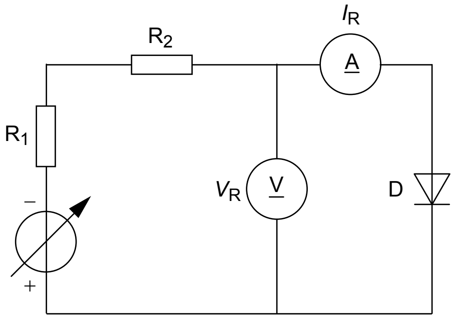


Figure 5 – Circuit diagram for the measurement of I_R

c) *Circuit description and requirements*

D diode being measured

R_1 calibrated resistor (pulse measurement only)

R_2 protective resistor

d) *Measurement procedure*

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of reverse voltage V_R across the diode.

The reverse current I_R is read from the ammeter A.

e) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- reverse voltage (V_R).

6.2.2 Forward voltage V_F

a) *Purpose*

To measure the forward voltage across a signal or switching diode under specified conditions.

b) Circuit diagram (Figure 6)

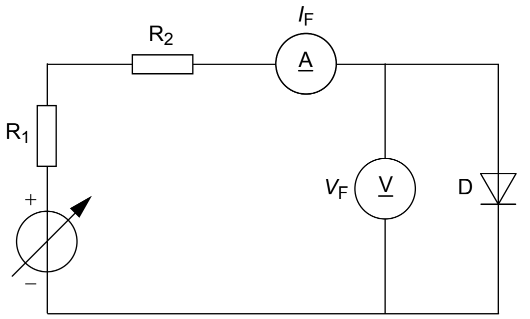


Figure 6 – Circuit diagram for the measurement of V_F

c) Circuit description and requirements

D diode being measured

R_1 calibrated resistor (pulse measurement only)

R_2 a high-value resistor

d) Measurement procedure

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of forward current I_F as measured on ammeter A.

The forward voltage V_F is read from the voltmeter V.

e) Specified conditions

- ambient or case temperature (T_a, T_c);
- forward current (I_F).

6.2.3 Total capacitance C_{tot}

a) Purpose

To measure the total capacitance of a diode under specified conditions.

b) Circuit diagram (Figure 7)

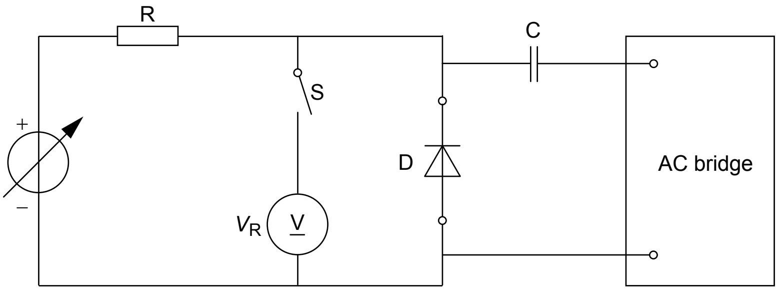


Figure 7 – Circuit diagram for the measurement for C_{tot}

c) Circuit description and requirements

D diode being measured

R low conductance resistor compared with the admittance of the diode being measured.

C capacitor C able to withstand the reverse bias voltage of the diode and to present a short-circuit at the frequency of measurement.

d) Precautions to be observed

If the measured capacitance is very small, the mounting conditions will affect the accuracy of the results and they should be specified.

e) Measurement procedure

The temperature is set to the specified value.

The voltage across the diode is adjusted to the specified value V_R. Then the voltmeter V is taken out of the circuit and the capacitance of the diode being measured is determined, using the a.c. bridge, by subtracting the value without the diode in its mounting from the value with the diode in its mounting.

f) Specified conditions

- ambient or case temperature (T_a, T_c);
- reverse voltage (V_R);
- measurement frequency, if different from 1 MHz;
- mounting conditions of the diode, if necessary.

6.2.4 Forward recovery time t_{fr} and peak forward recovery voltage V_{FRM}

a) Purpose

To measure the forward recovery time and the peak forward recovery voltage of the diode.

b) Circuit diagram (Figure 8)

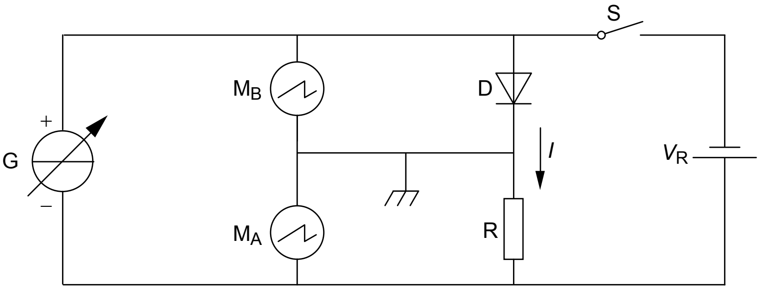


Figure 8 – Circuit diagram for the measurement of t_{fr} and V_{FRM}

c) Circuit description and requirements

D diode being measured

G current-pulse generator having a compliance voltage (open-circuit output voltage) of 50 V minimum or three times V_{FRM}, whichever is greater

R non-inductive calibrated resistor

S electronic switch, which is closed except for a period starting just before the current pulse and throughout its duration

M_A and M_B oscilloscopes or other monitoring instruments

The pulse duration shall be long enough for the forward voltage to have reached the stable value V_F.

The pulse duration and the duty cycle of the current-pulse generator should be such that negligible internal heating of the diode occurs.

d) Measurement procedure

The temperature is set to the specified value.

While monitoring the current waveform on M_A, the current-pulse source is adjusted to the specified conditions of rise time t_r and forward current I_{FM}.

The reverse voltage V_R is adjusted to the specified value, and switch S is appropriately set.

The peak forward recovery voltage V_{FRM} and the forward recovery time t_{fr} are measured on the waveform of voltage across the diode on M_B in accordance with the applied specification method.

e) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- peak forward current (I_{FM});
- rise time of current pulse (t_r) (between 10 % and 90 % of I_{FM}, unless otherwise stated);
- voltages defining the beginning and the end of the forward recovery time, if different from 10 % and 110 %, respectively, of V_F;
- reverse voltage (V_R).

6.2.5 Reverse recovery time (t_{rr}) and recovered charge (Q_r)

a) *Purpose*

To measure the reverse recovery time of a diode under specified switching conditions and to calculate the charge recovered from a diode when it is rapidly switched from a forward biased condition to a reverse biased condition.

b) *Circuit diagram (Figure 9)*

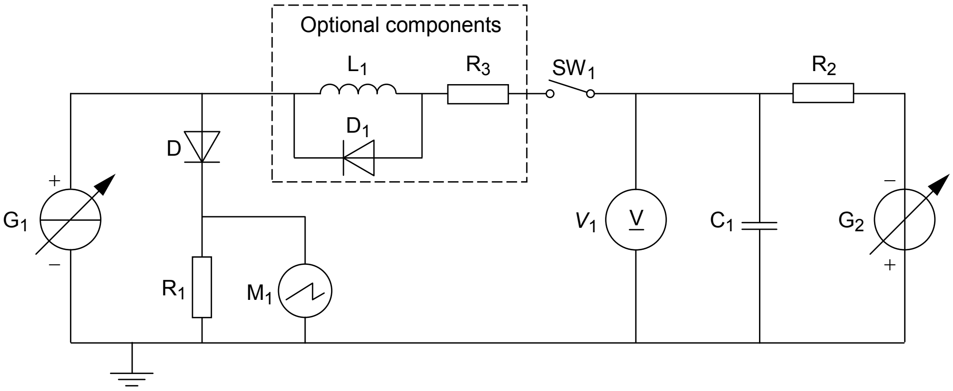


Figure 9 – Circuit diagram for the measurement of t_{rr}

c) *Circuit description and requirements*

D	diode being measured
G_1	current generator supplying the forward current (I_F)
R_1	non-inductive current shunt
M_1	measuring instrument (eg. oscilloscope)
SW_1	switch to turn off the diode
C_1	capacitor to provide the reverse current pulse, large enough to maintain the reverse voltage applied to the diode for at least three times t_{rr}max. while passing a current equal to $I_F + I_{rr}$. For example:

$$C_1 \min = \frac{20(I_F + I_{rr} \max) t_{rr} \max}{V_{rr} \max}$$

R_2	protective resistor for G_2
G_2	voltage generator to provide the specified reverse voltage as measured on V_1.

If a peak reverse current (I_{rr}max) is specified:

Set G_2 to V_R max and R_3 to V_R max/(I_F + I_{rr}max).

If the rate of change of current (dI/dt) is specified:

Set L_1 to $V_R$max/(dI/dt) and provide D_1 to clamp the voltage generated by L_1 when the diode being tested turns off.

d) *Measurement procedure*

The temperature is set to the specified value.

With SW_1 open, set G_2 to provide the reverse voltage to be applied to the diode as measured on V_1. Adjust G_1 to apply the forward current (I_F) as measured on M_1. After this current has been applied for at least the time necessary to ensure that the diode is fully charged, close switch SW_1. The resultant current pulse is recorded on the measuring instrument M_1.

Reverse recovery time is measured between the two points specified in 5.2.2.5 and recovered charge is calculated between the same two points using one of the following equations:

$$Q_r = \int_{t_0}^{t_0+t_I} I_R.dt \cdots\cdots or \cdots\cdots Q_r = \int_{t_0}^{t_0+t_{rr}} I_R dt$$

e) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- forward current (I_F);
- Reverse voltage (V_R) or reverse recovery current (I_{rr}max);
- Rate of change of current (dI/dt) (if required);
- End time t_I or $t_{rr.}$

6.2.6 Detector voltage efficiency η_v

a) *Purpose*

To measure the detector voltage efficiency of a signal diode under specified conditions.

b) *Circuit diagram (Figure 10)*

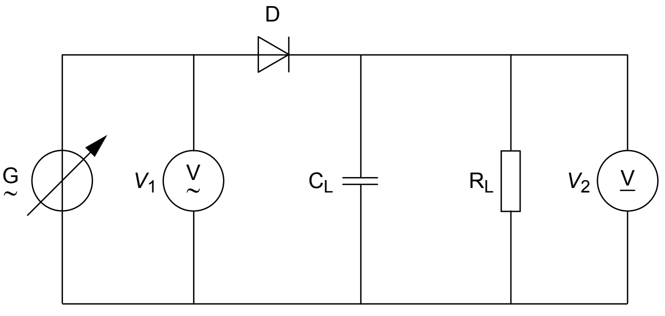


Figure 10 – Circuit diagram for the measurement of η_v

c) *Circuit description and requirements*

D diode being measured

G low-impedance generator

V r.m.s. reading voltmeter

The value of R_L should match the output impedance of the generator G. The time constant C_LR_L should be large compared to the reciprocal of the measurement frequency.

d) *Measurement procedure*

The temperature is set to the specified value.

The generator is adjusted to give the specified r.m.s. value of V_1.

V_2 is read from the voltmeter and the detector voltage efficiency is calculated using the expression:

$$\eta_v = \frac{V_2}{V_1\sqrt{2}} (\times 100\,\%)$$

e) Specified conditions

- ambient or case temperature (T_a, T_c);
- measurement frequency (usually 100 MHz);
- circuit parameters (R_L and C_L);
- voltage V_1 (r.m.s. value).

6.2.7 Detector power efficiency η_p

a) Purpose

To measure the detector power efficiency of a signal diode under specified conditions.

b) Circuit diagram (Figure 11)

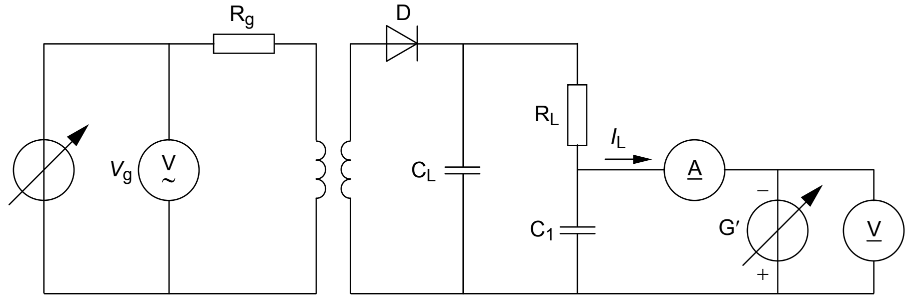


Figure 11 – Circuit diagram for the measurement of η_p

c) Circuit description and requirements

D diode being measured

G voltage generators

V voltmeter

A ammeter

The transformer should have a low loss, and the equivalent value of the loss resistance should be included in R_g.

The turns ratio of the transformer should be such as to ensure impedance matching between R_g and R_L.

The value of R_L should be high compared with the value of the forward impedance of the diode. The time constant $C_L R_L$ should be large compared to the reciprocal of the measurement frequency.

Capacitor C_1 should provide a short-circuit at the measurement frequency.

d) Measurement procedure

The temperature is set to the specified value.

The a.c. voltage generator is set to zero, and the d.c. voltage generator is set to give the specified forward bias conditions. The current I_{L1} is read from the d.c. ammeter A.

The a.c. voltage generator is set to the specified r.m.s. voltage V_g and the new value I_{L2} is read from the ammeter.

The detector power efficiency is calculated using the expression:

$$\eta_p = \frac{4(I_{L2} - I_{L1})^2 \cdot R_L \cdot R_g}{V_g^2} (\times 100\ \%)$$

e) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- measurement frequency (f) and r.m.s. voltage (V_g);
- d.c. bias conditions;
- circuit parameters (R_L and C_L);
- generator impedance (R_g).

6.2.8 Noise V_n, I_n

a) *Purpose*

To measure the noise current of a diode.

b) *Circuit diagram (Figure 12)*

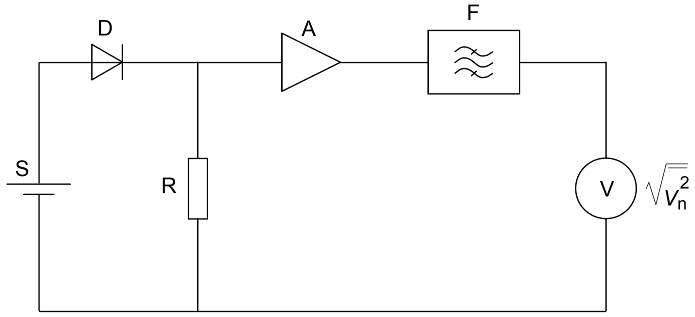


Figure 12 – Circuit diagram for the measurement of noise current

c) *Circuit description and requirements*

A low-noise amplifier
D diode being measured
F pass-band filter
R load resistor
S d.c. source
V square-law voltmeter

The diode may be biased in either direction to obtain noise values in either forward or reverse direction.

The recommended values for the limits of the pass-band of the filter are: 900 Hz and 1 100 Hz.

d) *Measurement procedure*

The voltage drop produced by the noise current of the diode is measured in the load resistor after amplification by means of a pass-band amplifier having a determined bandwidth and gain. At the output, the noise voltage is observed with a square-law voltmeter. The noise current in the pass-band is given as follows:

$$\sqrt{\overline{I_n^2}} = \frac{\sqrt{\overline{V_n^2}}}{A_v \, R}$$

where:

A_v = voltage amplification of the amplifier plus filter

The noise current may be brought back by calculation to 1 Hz of bandwidth.

e) *Precautions*

The noise introduced by the amplifier, the load resistance and the d.c. source shall be negligible. If this is not the case, it is necessary to make a correction obtained by measuring the noise with the diode replaced by an appropriate resistor.

f) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- frequency
- bandwidth
- forward current or reverse voltage

6.3 Voltage reference diodes and voltage regulator diodes

6.3.1 Working voltage V_Z

a) *Purpose*

To measure the working voltage corresponding to a specified working current.

b) *Circuit diagram (Figure 13)*

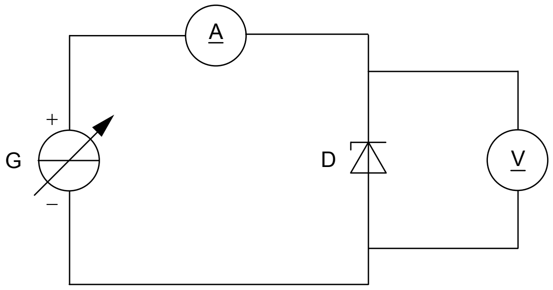


Figure 13 – Circuit diagram for the measurement of V_Z

c) *Circuit description and requirements*

D diode being measured

G current generator

A ammeter

V voltmeter

The voltmeter V should have a high resistance compared with the resistance of the diode at the working voltage.

d) *Measurement procedure*

The temperature is set to the specified value.

The output of the current generator G is increased until the specified working current is indicated on the ammeter. The working voltage across the diode is then read from the voltmeter.

e) *Specified conditions*

- ambient or case temperature (T_a, T_c);

- working current (I_Z);
- mounting conditions including length of leads, if necessary.

6.3.2 Differential resistance in the working current range r_z

a) *Purpose*

To measure the differential resistance at a specified working current.

b) *Circuit diagram (Figure 13)*

c) *Circuit description and requirements*

The working voltage V_z is measured at two currents using the method described in 6.3.1. Switching between the two currents may be implemented using an additional pulse or alternating current source.

d) *Measurement procedure*

The temperature is set to the specified value.

The current is set to a value 10 % above the specified working current and the voltage V_1 is read on the voltmeter.

The current is then set to a value 10 % below the specified working current and the voltage V_2 is read on the voltmeter.

The differential resistance is given by:

$$r_z = \frac{V_1 - V_2}{I_z(1{,}1 - 0{,}9)}$$

e) *Precautions*

Since the voltage difference to be measured is small relative to the working voltage, an accurate method of measuring the voltage is required.

f) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- working current (I_Z);
- mounting conditions including length of leads, if necessary.

6.3.3 Temperature coefficient of working voltage α_{vz}

a) *Purpose*

To measure the temperature coefficient of working voltage at a specified working current and over a specified ambient or case temperature range.

b) *Circuit diagram (*Figure 13*)*

c) *Circuit description and requirements*

The working voltage V_Z is measured at two specified temperatures T_1 and T_2 using the method described in 6.3.1.

d) *Measurement procedure*

The temperature is set to the lower specified value (T_1).

The current is set to the specified current (I_Z) and the voltage (V_{Z1}) is measured.

The temperature is set to the higher specified value (T_2).

The current is set to the specified current (I_Z) and the voltage (V_{Z2}) is measured.

The temperature coefficient is calculated using the expression:

$$\alpha_{vz} = \frac{100\left(V_{Z2} - V_{Z1}\right)}{\left(T_2 - T_1\right)V_{Z1}} \text{ (Percent per degree Celsius)}$$

e) *Precautions*

Ensure that the current is the same for both measurements.

As the voltage difference to be measured is small relative to the working voltage, an accurate method of measuring the voltage is required.

f) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- working current (I_Z);
- mounting conditions including length of leads, if necessary.

6.3.4 Reverse current I_R

The method for signal diodes in 6.2.1 applies.

6.3.5 Forward voltage V_F

The method for signal diodes in 6.2.2 applies.

6.3.6 Junction capacitance C_{tot}

The method for signal diodes in 6.2.3 applies.

6.3.7 Noise voltage V_n

a) *Purpose*

To measure the noise voltage of a reference diode under specified conditions.

b) *Circuit diagram (Figure 14)*

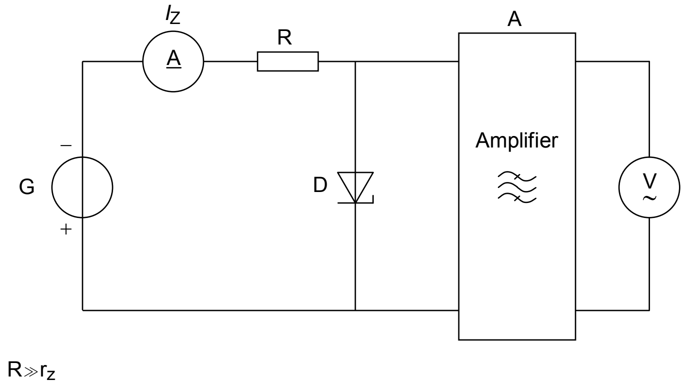


Figure 14 – Circuit diagram for the measurement of V_n

c) *Circuit description and requirements*

D	diode being measured
R	load resistor
G	dc source
A	selective amplifier having a stated bandwidth, a known amplification and a high-input impedance
V	r.m.s. voltmeter

d) *Precautions to be observed*

If the inherent noise is not negligible, the measured value shall be corrected accordingly.

e) *Measurement procedure*

G is set to give the specified working current (I_Z) as measured on ammeter A.

The noise voltage of the diode is measured after amplification by means of a pass-band amplifier having a determined bandwidth and gain. At the output, the noise voltage is observed with a square-law voltmeter. The noise voltage in the pass-band is given by the meter reading divided by the amplifier gain.

f) Specified conditions

- ambient or case temperature (T_a or T_c);
- working current and frequency of measurement (I_Z, f);
- noise detector bandwidth.

6.4 Current-regulator diodes

6.4.1 Regulator current I_S

a) Purpose

To measure the regulator current of a current-regulator diode at a specified regulator voltage.

b) Circuit diagram (Figure 15)

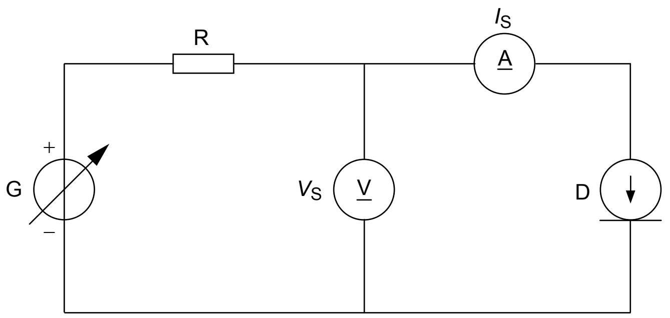


Figure 15 – Circuit diagram for the measurement of I_S

c) Circuit description and requirements

D	current-regulator diode being measured
G	d.c. voltage generator
R	protective resistor
A	ammeter
V	voltmeter

d) Measurement procedure

The temperature is set to the specified value.

The voltage generator is adjusted to obtain the specified value of regulator voltage V_S across the current-regulator diode.

The regulator current I_S is read from the ammeter A.

e) Specified conditions

- ambient or case temperature (T_a, T_c);
- regulator voltage (V_S);

6.4.2 Temperature coefficient of regulator current α_{IS}

a) Purpose

To measure the temperature coefficient of regulator current of a current-regulator diode at a specified regulator voltage.

b) Circuit diagram

See Figure 15.

c) *Circuit description and requirements*

The regulator current I_s is measured at two specified temperatures T_1 and T_2 using the method described in 6.4.1)

The current measuring device A shall have a high accuracy, because the difference of the two currents to be measured occurs in the formula for the temperature coefficient. Therefore, the measuring device A shall be for example based on a bridge or compensation method or shall be a digital voltmeter of high precision.

The ambient or case temperature shall be carefully controlled during the measurement. In the case of appreciable power dissipation within the device, thermal equilibrium shall be reached before the current measurements are made.

d) *Measurement procedure*

For a specified regulator voltage V_S as read from voltmeter V, the regulator current is measured at two specified values of ambient or case temperatures T_1 and T_2.

The temperature coefficient is calculated using the expression:

$$\alpha_{IS} = \frac{100\left(I_{S2} - I_{S1}\right)}{\left(T_2 - T_1\right) I_{S1}} \text{ (Percent per degree Celsius)}$$

where:

I_{S1} is the current measured at the lower temperature T_1

I_{S2} is the current measured at the higher temperature T_2

e) *Specified conditions*

– ambient or case temperatures (T_1 and T_2) (T_a, T_c)

– regulator voltage (V_S)

6.4.3 Regulator current variation ΔI_S

a) *Purpose*

To measure the regulator current variation of a current-regulator diode over a specified regulator voltage range.

b) *Circuit diagram*

See Figure 15.

c) *Circuit description and requirements*

The regulator current I_S is measured at two specified voltages V_{S1} and $V_{S2.}$

d) *Measurement procedure*

The variable voltage generator is adjusted to the lower specified value V_{S1}; the regulator current I_{S1} is read from the ammeter A.

The variable voltage generator is adjusted to the higher specified value V_{S2}; the regulator current I_{S2} is read from the ammeter A.

The regulator current variation is then calculated using the expression:

$$\Delta I_S = I_{S2} - I_{S1}$$

e) *Specified conditions*

– ambient or case temperature (T_a, T_c)

– regulator voltages (V_{S1}, and V_{S2})

6.4.4 Limiting voltage V_L

a) *Purpose*

To measure the limiting voltage of a current-regulator diode at a specified current.

b) *Circuit diagram*

See Figure 15.

c) *Circuit description and requirements*

The limiting voltage V_L is measured at the specified limiting current I_L.

d) *Measurement procedure*

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of current I_L through the current-regulator diode and the voltage is measured on voltmeter V_s.

e) *Specified conditions*

- ambient or case temperature (T_a, T_c)
- limiting current (I_L)

6.4.5 Small-signal regulator conductance g_s

6.4.5.1 Two-voltmeter method

a) *Purpose*

To measure the small-signal regulator conductance of a current-regulator diode under specified regulator voltage.

b) *Circuit diagram (Figure 16)*

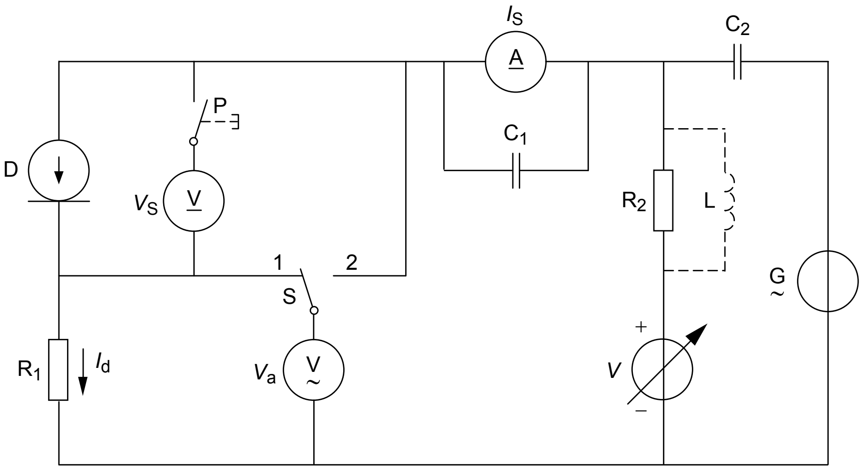


Figure 16 – Circuit diagram for the measurement of g_s (two-voltmeter method)

c) *Circuit description and requirements*

D	current-regulator diode being measured
R_1	The value of this resistor shall be sufficiently low with respect to $1/g_S$; in practice, a value of 10 Ω to 100 Ω will be used, depending on the voltmeter sensitivity.
R_2	The value of this resistor shall be sufficiently high with respect to the generator resistance.
L	The inductance is optional; its use facilitates the adjustment of the specified operating point.
C_1, C_2	These capacitances shall represent an effective short-circuit at the measurement frequency.
P	The push-button switch shall only be used for measuring V_S.
V_a	The voltmeter shall have sufficient sensitivity; for the measurement of low inductances, it shall preferably be a selective instrument.

d) Measurement procedure

The temperature is set to the specified value.

The variable voltage generator G is adjusted to obtain the specified continuous voltage V_S across the current-regulator diode.

With the switch S in position 1, the value $V_1 = I_d R_1$ is measured on voltmeter V_a, while with the switch S in position 2, the value $V_2 = V_s + I_d R_1$ is measured, where V_S is the a.c. voltage drop across the current-regulator diode.

$$V_2 - V_1 = V_S$$

$$I_d = \frac{V_1}{R_1}$$

The small-signal conductance g_s is then calculated using the following expression:

$$g_s = \frac{I_d}{V_S} = \frac{V_1}{R_1 \left(V_2 - V_1\right)}$$

For $V_2 >> V_1$:

$$g_s \approx \frac{V_1}{R_1 V_2}$$

e) Specified conditions

- ambient or case temperature (T_a, T_c);
- regulator voltage (V_S);
- frequency of measurement (f).

6.4.5.2 Two-terminal bridge method

a) Purpose

To measure the small-signal regulator conductance of a current-regulator diode under specified regulator voltage.

b) Circuit diagram (Figure 17)

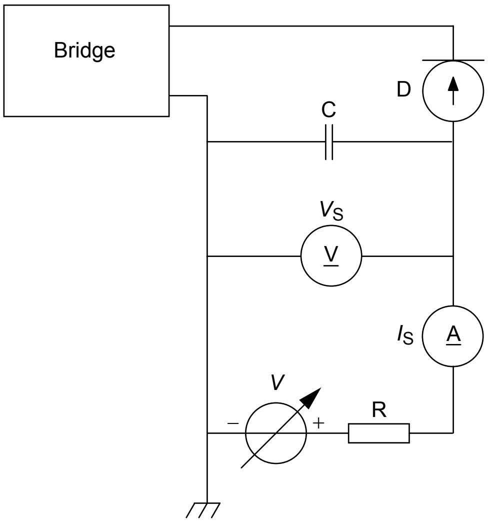


Figure 17 – Circuit diagram for the measurement of g_s (two-terminal bridge method)

c) *Circuit description and requirements*

D	current-regulator diode being measured
Bridge	bridge with a low d.c. resistance between its input terminals and able to carry the required current without affecting the accuracy of the measurement.
C	capacitor providing an effective short-circuit at the frequency of measurement
R	protective resistor

d) *Measurement procedure*

The temperature is set to the specified value.

The bridge is first balanced with the current-regulator diode removed.

The device being measured is inserted into the measurement socket and, with the specified regulator voltage applied, the bridge is again balanced.

g_s is then read from the bridge.

e) *Specified conditions*

- ambient or case temperature (T_a, T_c);
- regulator voltage (V_S);
- frequency of measurement (f).

6.4.6 Knee conductance g_k

The same measuring method as in 6.4.5 above for small-signal conductance can be used, with the regulator voltage set to the specified value of V_K.

7 Acceptance and reliability

Clause 7 of IEC 60747-1:2006 and its subclauses apply.

7.1 Acceptance-defining characteristics

Acceptance-defining characteristics, their criteria and measurement conditions are listed in Table 3.

Characteristics shall be measured in the sequence in which they are listed in this table, because the changes of characteristics caused by some failure mechanisms may be wholly or partially masked by the influence of the other measurement conditions.

Table 3 – Acceptance-defining characteristics for acceptance after endurance tests

Device sub-categories	Acceptance defining characteristics	Acceptance criteria	Measurement conditions
Signal and switching diodes	I_R	$\leq USL$	Highest V_R specified for I_R (Note 4)
	V_F	$\leq USL$	Highest I_F specified for V_F
Voltage-reference diodes	I_R	$\leq USL$	Highest V_R specified for I_R
	V_Z	$\lvert\Delta\rvert < 1\ \%$ of IVD (Note 2) $\lvert\Delta\rvert < 2\ \%$ of IVD (Note 3)	I_Z specified for nominal V_Z
	r_Z	$\leq USL$	
	V_{nz}	$\leq USL$	See the relevant specification
Voltage-regulator diodes	I_R	$\leq USL$	Highest V_R specified for I_R
	V_Z	$\leq USL$ $\geq LSL$	I_Z specified for nominal V_Z
	r_z	$\leq USL$	
Current-regulator diodes	V_L	$\leq USL$	Highest I_L specified for V_L
	I_S	$\leq USL$ $\geq LSL$	V_S specified for nominal I_S
	g_S	$\leq USL$	

NOTE 1 USL = upper specification limit

LSL = lower specification limit

IVD = initial value of individual device

NOTE 2 For devices which are specified with a tolerance less than or equal to 1 %.

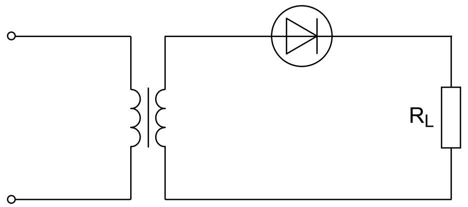
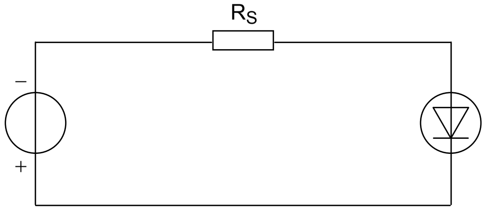
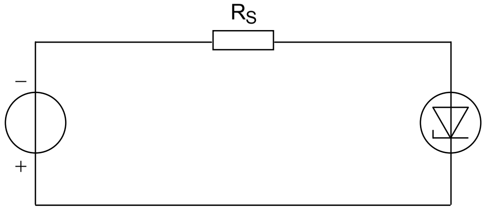
NOTE 3 For devices which are specified with a tolerance greater than 1 %.

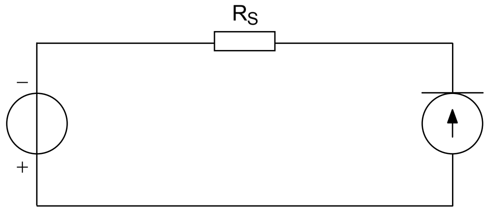
NOTE 4 Where the V_R specified for I_R measurements is in the breakdown region, a lower value of V_R may be used.

7.2 Electrical endurance tests

The following Table 4 shows the test circuits and conditions for the endurance tests.

Table 4 – Test circuits and conditions for the endurance tests

Device sub-categories	Tests	Operating conditions			Test circuits	Remarks
		Current	Voltage	Temperature		
Signal diodes	Operating life	Equivalent to a value which gives power dissipation P_{tot}max. or maximum specified average rectified current	Sine wave 50 Hz or 60 Hz Peak value = $V_R$max.	(See 7.2.4 of IEC 60747-1[a])	 IEC 1465/13	R_L = load resistor
	High-temperature reverse bias		$V_R = V_R$max.	Highest operating temperature at which V_R applies at $T_a$max. or $T_c$max. as specified	 IEC 1466/13	R_S = current limiting resistor
Voltage-reference diodes and voltage-regulator diodes	Operating life	I_z max. as given in the relevant specification	Depends on I_z	(See 7.2.4 of IEC 60747-1[a])		R_S = current limiting resistor $Rs \geq 0{,}2\frac{Vz}{Iz}$

Device sub-categories	Tests	Operating conditions			Test circuits	Remarks
		Current	**Voltage**	**Temperature**		
Current-regulator diodes	Operating life	V_S max. as given in the relevant specification	Depends on V_S	(See 7.2.4 of IEC 60747-1[a])		R_S = current limiting resistor

[a] See IEC 60747-1:2006 and its Amendment 1:2010.

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